FORCED VIBRATION TEST OF A REACTOR BUILDING AND ITS ANALYTICAL STUDIES

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SUMMARY

The forced vibration tests for the BWR reactor building were performed by applying sinusoidal excitation on the refueling floor. From these tests, the basic dynamic characteristics such as the vibration modes and frequency response characteristics were obtained. The simulation analysis was performed by using multi-stick mathematical model, with consideration to the frequency dependent stiffness of soil, and the results showed very good agreement with the test results.

INTRODUCTION

In the construction of a nuclear power plant, the behavior of important facilities such as the reactor building during an earthquake are evaluated by carrying out dynamic analyses. Hence, it becomes very important to analyze the results of the forced vibration tests and earthquake observations and to confirm the adequacy of these analyses. This paper describes the results of the forced vibration tests of a 1100MWe BWR type reactor building by use of large size vibration generators and its simulation analyses.

OUTLINE OF FORCED VIBRATION TESTS

The plot plan of the nuclear power plant is shown in Fig.-1. The forced vibration tests were performed by applying sinusoidal excitation in the horizontal direction with 2 units of vibration generator on the refueling floor of the reactor building as illustrated in Fig.-2. The vibration generators were installed as shown in Fig.-3. These large vibration generators are eccentric mass type, with maximum exciting force of 150 tons per unit (at 13 Hz), owned by the Central Research Institute of Electric Power Industry. The exciting force of the vibration generators actually used for the test is shown in Fig.-4. The measuring system has the capability to eliminate miscellaneous vibration by means of calculating the cross correlation functions of the sinusoidal signal from the vibration generator and the measurement signals. The reactor building is a large and heavy structure made of reinforced concrete, which plane dimensions are 75.5ms square in the lower portion and 46.2ms x 48.7ms at the upper portion. The total height of the building is 75.3ms with 17.5ms under ground and 57.8ms above ground. The total weight is approximately 260,000 tons.

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The forced vibration tests were performed under the following conditions:

1) The construction of the structure of the reactor building and the turbine building and the installation of the main equipment were about complete.

2) The reactor building and the turbine building were structurally isolated with a space of 5cms in-between.

3) The top heads of PCV and RPV and the shield plug were placed temporarily on the refueling floor.

4) There was water in the suppression chamber, but none in the fuel pool.

RESULTS OF FORCED VIBRATION TESTS

The results of the forced vibration tests, e.g. the resonance curves and phase lag curves of the representative measuring points, are shown in Fig.-5 and 6. The vertical axis of the resonance curves is the displacement amplitude normalized by the exciting force of 1 ton, and that of the phase lag curves is shown in terms of degree with the phase lag from the exciting force as plus sign.

The considerations obtained from the results of the tests are as follows:

1) The first predominant frequency of the reactor building coupled with the soil layer is about 3.0Hz.

2) In the vicinity of 8.0Hz, the horizontal motion of the roof floor predominates, while other parts have small amplitudes due to its energy absorption effect.

3) The second vibration mode shape of the reactor building presents its peak in the vicinity of 9.5Hz.

4) The damping factor being calculated from the primary horizontal resonance curve of the refueling floor by means of Half Power Method is approximately 33%.

5) The phase lag from the exciting force increases as the measuring point becomes closer to the basement slab, and particularly, that of the horizontal motion of the basement slab is extremely large. This indicates that the radiation energy from the embedded part is large.

SIMULATION ANALYSES

Simulation analyses were performed to study the results of the forced vibration test in detail. As for the analytical model, the reactor building was divided into three zones, namely, shield wall, inner box wall and outer box wall. Each zone was replaced by lumped mass system as shown in Fig.-7, in which each wall was represented by bending shear springs and each slab by shear springs. Three zones were divided by straight lines bisecting the outer box wall and the inner box wall and by the lines bisecting the shortest distance of the inner box wall and the shield wall. In this analytical model, the shearing sectional area and the geometrical moment of inertia of the walls considered to be effective at the strain level of the forced vibration test was added to those of the sections to be evaluated for design.

The sections of the building for design were evaluated as followes:

(Evaluation of shearing sectional area)

Shield wall ..... One half of total sectional area
Box wall .... Total area of the walls in parallel with the exciting direction.

(Evaluation of geometrical moment of inertia)

Shield wall and inner box wall .... Total area
Outer box wall .... Effective flange width = L/4

(L: The length of a side of flange part)

Two cases of analyses were carried out regarding the soil stiffness under the foundation. In case-1, the frequency dependent characteristics of the soil are considered, presuming the real part of the soil stiffness as the curve of second degree. In case-2, the real part of the soil stiffness is assumed to be constant in the frequency range as conventionally used. (Refer to Fig.-8) The evaluation method[1] by M. Novak was used for the horizontal stiffness of the soil at the side of embedded parts of Kss, Ks1 and Ks2. In the simulation analysis, the complex type equation of motion was adopted as shown in the formula (1).

$$[M]\cdot\{\ddot{x}\} + ([K_R] + i[K_I])\cdot\{x\} = P\cdot e^{i\omega t} \quad \cdots\cdots \quad (1)$$

The complex stiffness of the building was calculated by the following formulas.

$$[{}_BK_R] = \sum_1^n (1 - 2h_j^2)\cdot k_j \quad \cdots\cdots \quad (2)$$

$$[{}_BK_I] = \sum_1^n (2h_j\sqrt{1 - h_j^2})\cdot k_j \quad \cdots\cdots \quad (3)$$

where: $[{}_BK_R]$: the real part of the stiffness matrix of the building
$[{}_BK_I]$: the imaginary part of the stiffness matrix of the building
h_j : the damping factor of member j
k_j : the stiffness of member j

The complex stiffness matrix in the formula (1), the soil stiffness as shown in Fig.-8 was added to the complex stiffness of the building, at each step of the frequency.

The analytical results are shown in Fig.-9 and 10. From these results, the following can be considered.

1) The analytical results of case-1 are in good agreement with the test results. Especially, the difference of the responses between the web part and the flange part of the inner box wall is well expressed at the peak in slightly less than 10.0Hz, which manifests the trial of zone-dividing worked out effectively in the evaluation of analytical model building dimension herein.

2) In the results of case-2, the peak in slightly less than 10.0Hz as described in 1) is not expressed. Therefore, the frequency dependent characteristics of soil stiffness should be taken into consideration.

3) The vertical motions of the center and the edge of the flange part of inner box wall are expressed by multiplying the rotational angle by arm length, and they are in good agreement with the test results.

CONCLUSION

The analytical results of case-1 were in good agreement with the test results of resonance curves and phase lag curves, which clarified the propriety of this analytical model. Namely, even by a simple zone-dividing method like this model, the difference of partial response characteristics of the building can be well expressed. Furthermore, it is proved that the analytical results correspond well with the test results by considering the frequency dependent characteristics of soil stiffness by approximately replacing the real part of soil stiffness into the curve of second degree.

ACKNOWLEDGEMENT

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REFERENCE

1) Milos Novak et al: Dynamic Soil Reaction for Plain Strain Case, ASCE, vol., EM4. August, 1978.

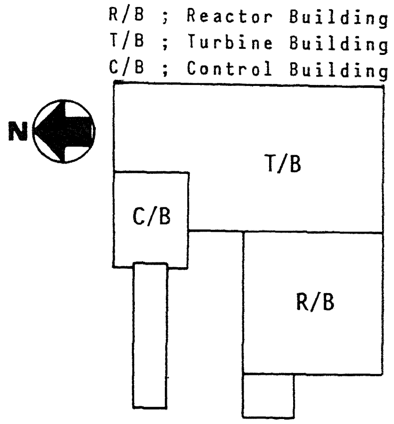


Fig.-1 Plot Plan

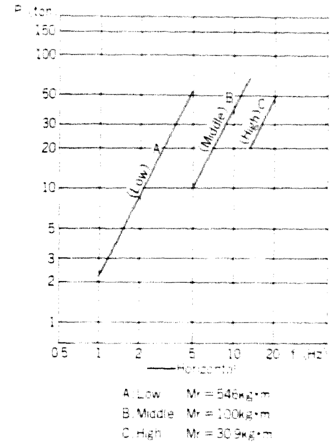


Fig.-4 Exciting Force

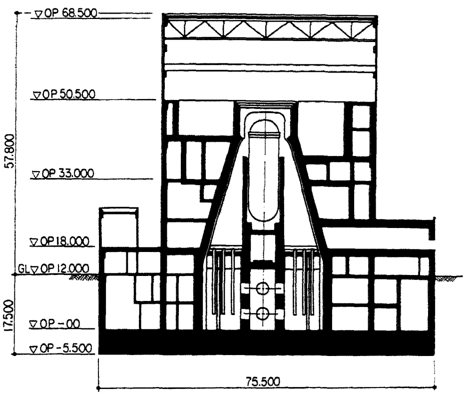


Fig.-2 Outline of Reactor Building

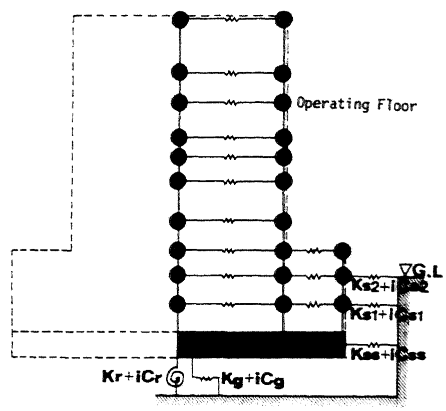
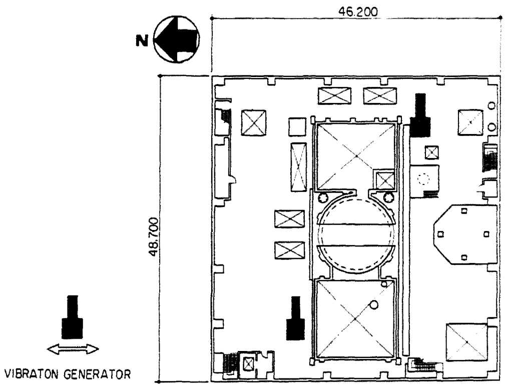


Fig.-7 Analytical Model



(Operating Floor)

Fig.-3 Location of Vibration Generators

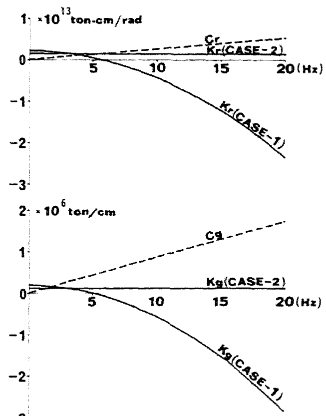


Fig.-8 Soil Stiffness under the Foundation

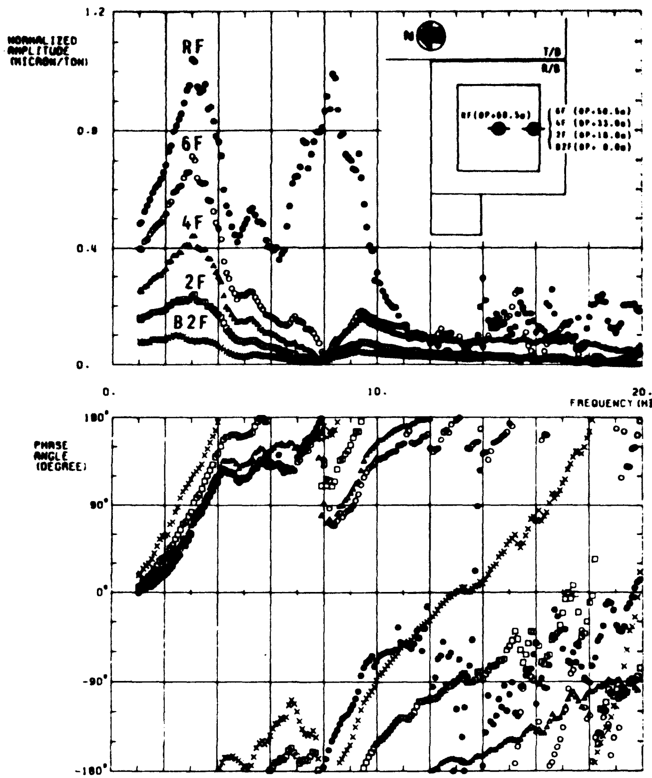


Fig.-5 Test Results (Horizontal Motion)

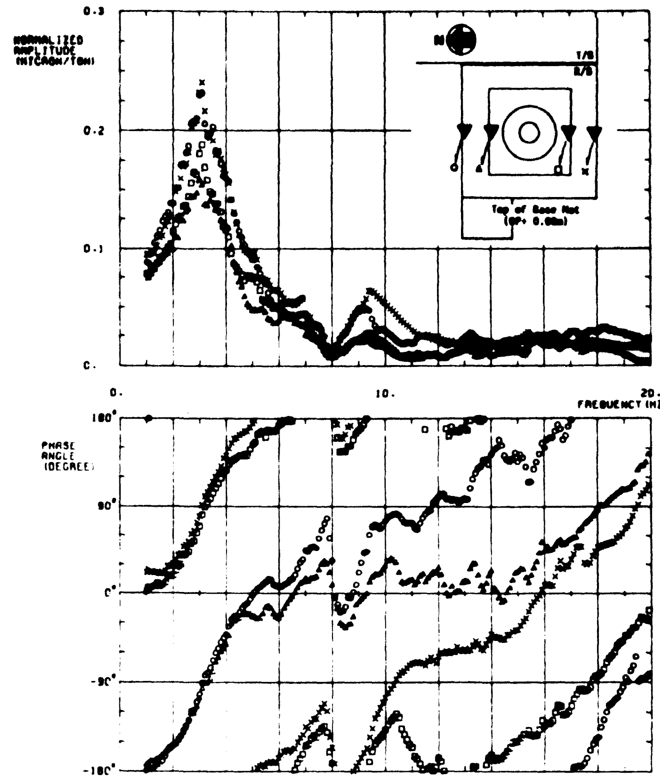
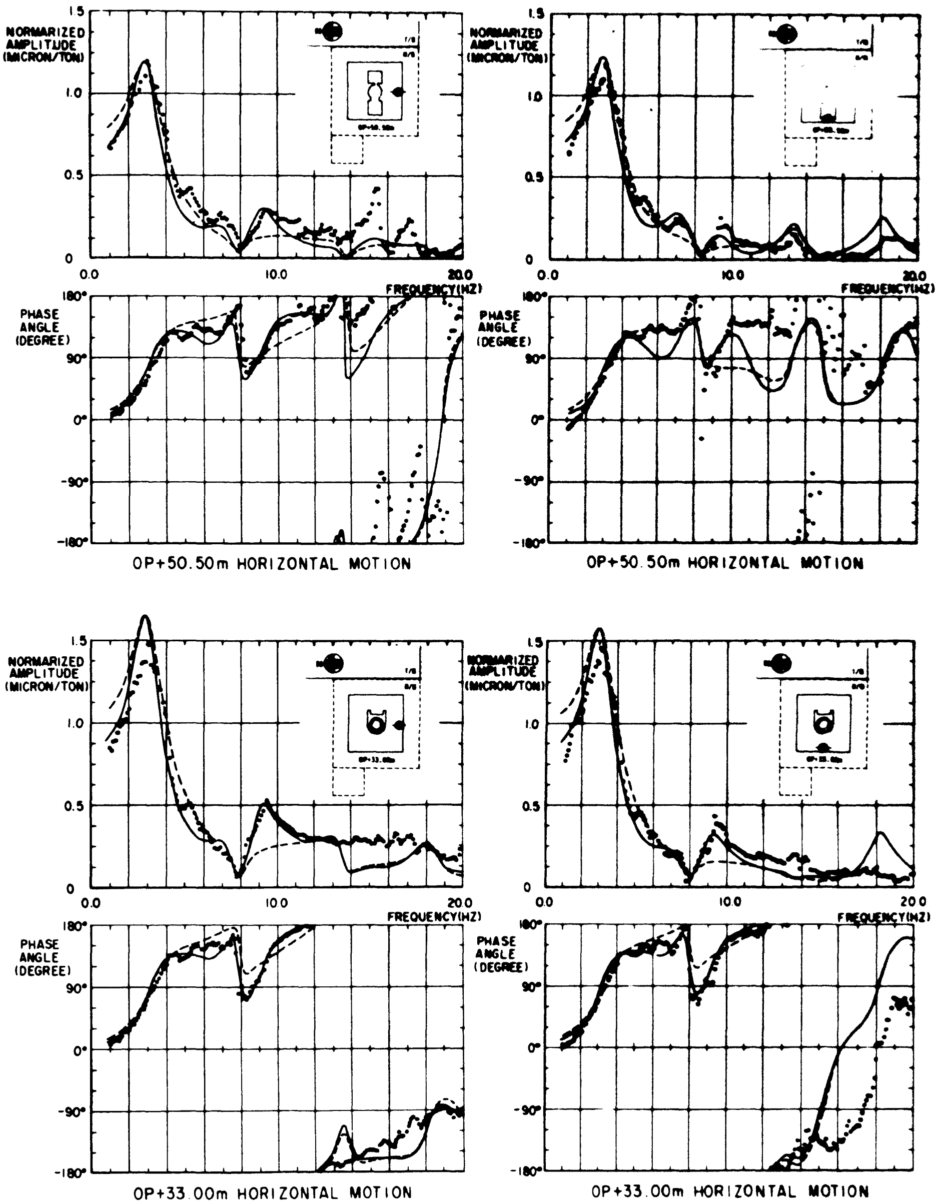
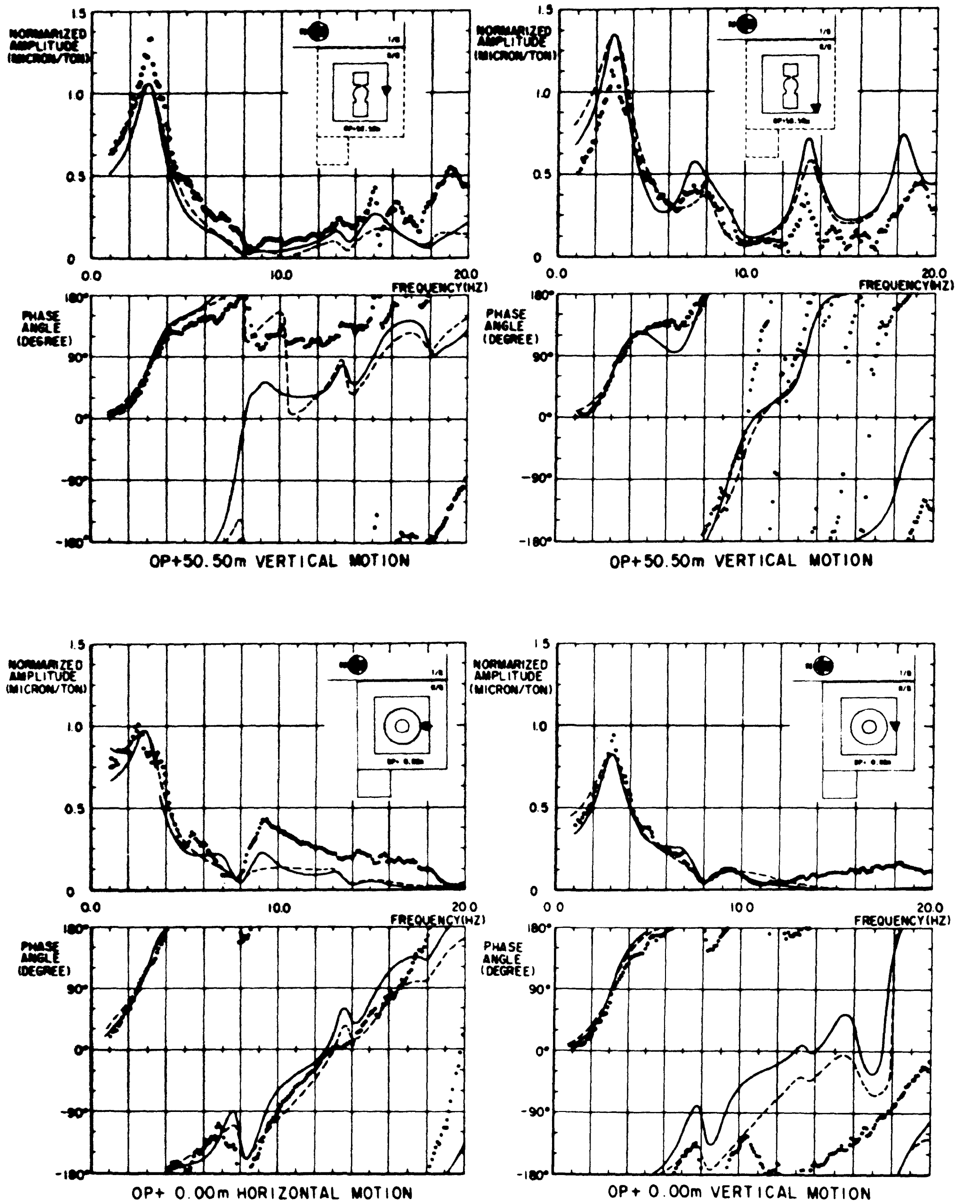


Fig.-6 Test Results (Vertical Motion)



·········· Test
——— Computed(Case-1)
------ Computed(Case-2)

Fig.-9 Comparison of Test Result with Computed



·········· Test
——— Computed(Case-1)
- - - - - Computed(Case-2)

Fig.-10 Comparison of Test Result with Computed